WASHINGTON STATE UNIVERSITY
PIERCE COUNTY EXTENSION

Technical Memorandum

BIORETENTION SOIL MIX REVIEW AND RECOMMENDATIONS FOR WESTERN WASHINGTON

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Date: January 2009

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Executive Summary

The soil mix used in bioretention systems is central for determining flow control and water quality treatment performance. The purpose of this study is to provide bioretention soil mix (BSM) guidelines that: 1) meet performance objectives; 2) include materials readily available in the Puget Sound region; 3) include materials that aggregate and compost suppliers can provide with adequate quality control and consistency; and 4) are affordable.

The focus of this study is on the aggregate component of the BSM. Four candidate aggregate samples were collected from various suppliers and locations around Puget Sound. Laboratory analysis was conducted to determine aggregate gradation, as well as the organic matter content, hydraulic conductivity, cation exchange capacity, and available phosphorus of a specified aggregate compost bioretention soil mix.

Hydraulic conductivity of bioretention soil mixes is strongly correlated to percent mineral aggregate passing the 200 sieve and that the fines should be less than five and ideally between two and four percent. Organic matter and cation exchange capacity of bioretention soil mixes meet or exceed Washington Department of Ecology's requirements for enhanced treatment. Recent research indicates excellent treatment for metals, hydrocarbons and sediment at moderate and higher infiltration rates. Accordingly, a relatively high infiltration rate will likely provide adequate soil contact and provide an equivalent media for enhanced treatment and protecting groundwater quality. Given this analysis and the expanded body of water quality treatment data for bioretention, the Department of Ecology now accepts an upper infiltration rate of 12 inches per hour for water quality treatment soil mixes when the BSM has the following characteristics: a CEC ≥ 5 meq/100 grams of dry soil; 8-10 percent organic matter content; 2-5 percent fines passing the 200 sieve; and a minimum soil depth of 18 inches with the above qualities.

Organic matter content and associated available phosphorus and nitrogen cycling in these mixes may lead to phosphate and nitrate exported in under-drain effluent. Current research shows variable nitrate and phosphate retention and additional work is needed to study methods to optimize bioretention soil mixes for phosphate and nitrate retention and removal capability. Due to budget constraints this study examines a small number of aggregate and aggregate compost samples. The City of Seattle has also completed a similar study examining a larger set of soil samples that can be used in conjunction with this work to improve bioretention design. That study is available at: www.seattle.gov/util/naturalsystems under technical resources.

Funding
This project was produced through funding from the U.S. Environmental Protection Agency and Washington State and administered by the Puget Sound Partnership.

1.0 Background

Bioretention is one of the most commonly applied and adaptable integrated management practices in the low impact development approach. Primary for the design and successful application of bioretention are the soil mix and plants that, working together, provide flow control and a highly effective filter media for many stormwater pollutants.

Soil mixes for bioretention areas need to balance three primary design objectives to provide optimum performance:

- Provide high enough infiltration rates to meet desired surface water drawdown and system dewatering.
- Provide infiltration rates that are not too high in order to optimize pollutant removal capability.
- Provide a growth media that supports long-term plant and soil health.

Different bioretention soil mixes can meet these design objectives; however, the purpose of this study is to provide BSM guidelines that: 1) meet the above design objectives; 2) include materials readily available in the Puget Sound region; 3) include materials that aggregate and compost suppliers can provide with adequate quality control and consistency; and 4) are affordable.

The BSM guidelines in the Low Impact Development Technical Guidance Manual for Puget Sound (Puget Sound Partnership and WSU Pierce County Extension, 2005) produce a BSM that adequately balances the three primary objectives. The aggregate component in the guidelines (loamy sand) is a soil type that is low in fines (passing 200 sieve), high in sand, and provides a long-term infiltration rate at or above 1 inch per hour (Washington State University Department of Biological Systems Engineering, Soil Texture Triangle: Hydraulic Properties Calculator). However, loamy sand is a type of topsoil that generally does not have a grain size distribution specification and is highly variable depending on the source. As a result, the BSM can have higher than desired fines which may result in lower than desired infiltration rates.

2.0 Methods

This study was conducted in three phases: 1) A readily available and relatively consistent aggregate material was identified as potentially suitable for a BSM; 2) The correct compost and aggregate mixture was determined and the BSM tested at a specific compaction for permeability; 3) The mix was evaluated for cation exchange capacity and a Bray test conducted for phosphorus availability.

2.1 Phase One

Thirteen soil, aggregate and compost suppliers were contacted from all regions of Puget Sound. From these contacts, screened or utility sand emerged as a candidate for further testing. Screened or utility sand is a readily available and fairly consistent material that contains some fine material (approximately 1-5 percent passing 200 sieve).

Screened or utility sand samples were then collected from three suppliers in various locations, including:

- Green Earth Technologies, Bellingham (two samples: C33 washed sand and screened sand).
- Fred Hill Materials, Poulsbo (one sample: screened sand).
- Miles Sand and Gravel, Roy Pit (one sample: utility sand).

2.2 Phase Two

Once the aggregate material was identified, the correct compost to aggregate mixture for the BSM was determined and then tested for grain size distribution, organic material content and permeability at a specific compaction rate. To attain the desired BSM organic matter content (approximately 10 percent by weight) the compost to aggregate ratio was determined by the following method. Compost is typically 40-50 percent organic matter (use 50 percent). Compost weighs approximately 50 percent as much as loam and a mix that is 40 percent compost by volume is roughly 20 percent organic matter by volume. Compost is about 50 percent as dense as the aggregate material, so the mix is approximately 10 percent organic matter by weight. Shannon and Wilson, Inc. was retained to conduct the soil analysis. The soil mix and testing procedure followed recommendations in the Low Impact Development Technical Guidance Manual for Puget Sound and include:

- Sieve analysis to determine grain size distribution (see Appendix 1, Figure 1 for results).
- Mix compost with aggregate to produce a BSM with approximately 10 percent organic material content by dry unit weight (samples tested at 8-10 percent, see Table 1 for results).
- Determine the organic matter content before and after permeability test using ASTM D2974 (Standard Test Method for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils). See Table 1 for results.
- Determine compaction characteristics of the BSM for the permeability test using ASTM D 1557 Method B (Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort). Eighty-five percent of maximum dry density was selected for the permeability tests to estimate field compaction where the BSM is placed in lifts and lightly boot packed (See results in Appendix 1, figures 2, 3, 4 and 5).
- Determine permeability or hydraulic conductivity of the BSM using ASTM D 2434 (Standard Test Method for Permeability of Granular Soils). See Table 1 and Appendix 1 tables 1-4 for results.

2.3 Phase Three

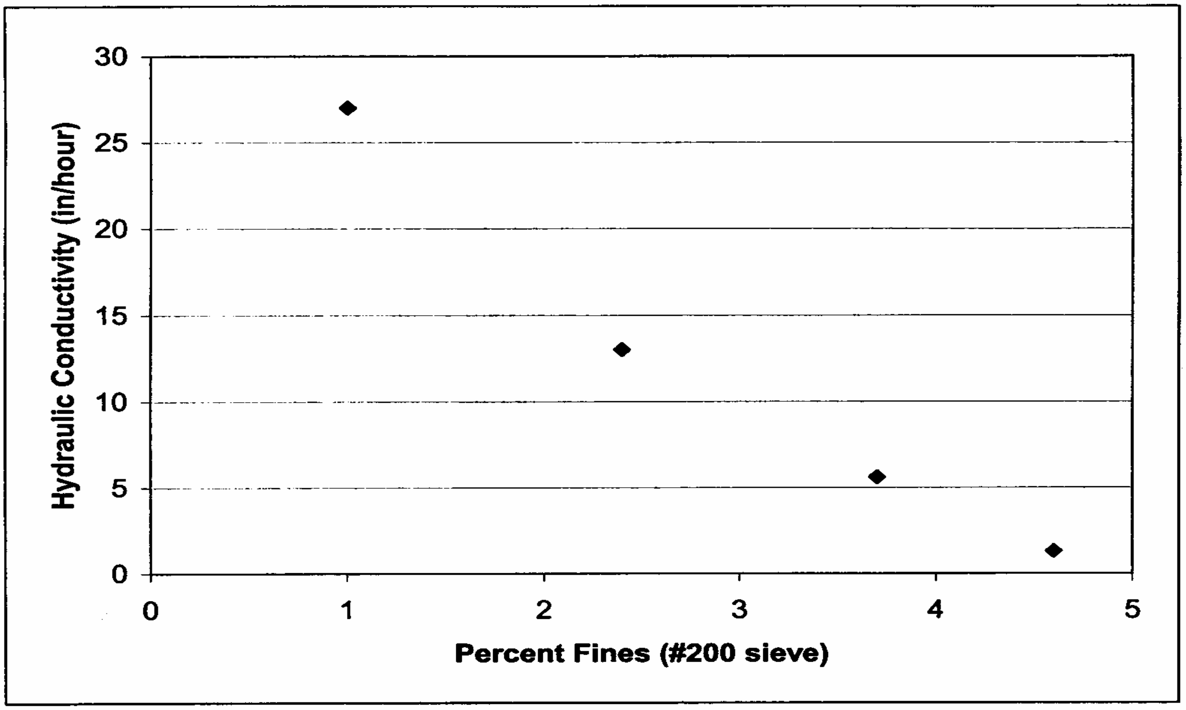
Evaluate the BSM for cation exchange capacity and conduct a Bray test. Cation exchange capacity is a measure of a soil's ability to adsorb certain stormwater pollutants and the Bray test determines, in part, the phosphorus availability of soils. Phosphorus (P) is a limiting nutrient in fresh water systems and a pollutant of concern in stormwater. Low plant or bio-available phosphorus (determined by the Bray test in western Washington) suggests that a soil will be more effective at reducing P concentrations in bioretention effluent (Hunt et al., 2006).

3.0 Results and discussion

Bioretention soil mixes often have a topsoil component that contains some percentage of organic matter. When topsoil is a component of the mix, 30-35 percent compost is typically used to attain 10 percent organic matter by weight. The aggregate material supplied for these tests has very little or no organic material; accordingly, the volumetric ratio of aggregate to compost was increased to 40 percent compost and 60 percent screen or utility sand. Test results in Table 1 show an organic matter content very close to 10 percent and indicate that this is an appropriate ratio to meet current guidelines for these mixes.

Compaction, percent fines (passing 200 sieve) and how well-graded the material is (coefficient of uniformity) strongly influence BSM hydraulic conductivity (Fowler and Robertson, 2007). One value of relative compaction (85 percent of maximum dry density) was selected as representative of typical field conditions in bioretention areas that do not have regular foot traffic. At constant relative compaction, the percent fines (passing 200 sieve) is a strong controlling factor in the permeability test (see Figure 1).

Figure 1: Percent fines of the four aggregate samples vs. hydraulic conductivity



3.1 Infiltration Rate

Under current guidelines, 1 inch per hour is recommended as a minimum infiltration rate for bioretention soil mixes to provide desired surface water drawdown and system dewatering for many management scenarios. For infiltration facilities, the long-term infiltration rate is determined by applying an infiltration reduction factor to account for possible degradation over time from sediment or other factors. A reduction factor of 2 (multiply measured BSM infiltration rate by 0.5) is applied where contributing areas are <5,000 sq. ft. of pollution generating surface, <10,000 sq. ft. of impervious area, and < 3/4 acre of landscape area. Above these thresholds an infiltration reduction factor of 4 (multiply measured BSM infiltration rate by 0.25) is applied (see the Low Impact Development Technical Guidance Manual for Puget Sound, 2005, pages 71-74 for more detail). Accordingly, measured infiltration rates should be a minimum of approximately 2 to 4 inches per hour to meet infiltration requirements.

Bioretention soil mixes provide the necessary characteristics for enhanced treatment. To meet the criteria for Department of Ecology's SSC-6 "Soil Physical and Chemical Suitability for Treatment" the maximum infiltration rate should be 2.4 inches per hour, the soil depth at least 18 inches, and the CEC at least 5 meq/100 grams of dry soil (Ecology, 2005). This maximum infiltration rate guideline was established for water quality treatment in existing or native soils and not for soil mixes designed for water quality treatment.

Bioretention soil mixes have high organic matter content and cation exchange capacities exceeding the above criteria (see tables 1 and 3). Additionally, recent water quality treatment research for bioretention soils suggest that higher infiltration rates may be appropriate. Hsieh and Davis (2005) found excellent removal of oil and grease and lead (Pb) and consistent removal of total phosphorus (TP) in similar bioretention soil mixes with significantly different infiltration rates (differences in infiltration a result of using different types of sand in the mix). At 6.61 in/hr, 22.44 in/hr and 9.45 in/hr mass removal for oil and grease was >96 percent and Pb >98 percent for all infiltration rates, and TP was 47, 41 and 48 percent respectively. In the same analysis, percent mass removal for TSS, oil and grease and Pb was >96, >96 and >97 percent respectively at 127.56 in/hr. Davis et.al. (2003) found relatively small differences in, but still very good, removal capabilities for total metals in bioretention soil mixes with different infiltration rates. At 0.79 in/hr copper (Cu), Pb and zinc (Zn) removal was 99, 97 and 95 percent respectively. At 3.19 in/hr percent mass removal for Cu, Pb and Zn was 87, 95 and 85 percent respectively.

The evaluations above vary from Washington Department of Ecology guidelines for enhanced treatment (i.e. influent concentrations are generally higher and total instead of dissolved metals are examined). However, this and other research suggest that removal of metals and hydrocarbons may remain high at infiltration rates above 2.4 in/hr in bioretention systems. Nitrate and ortho-phosphate retention and removal is likely influenced by plants, organic matter and soil structure, as well as (and central to this discussion) soil oxygen levels, soil water content, and hydraulic residence time. Accordingly, infiltration rate may play an important role for nitrate and phosphate management in bioretention systems, and more research is needed for defensible infiltration rate guidelines.

To provide adequate soil contact and provide an equivalent media for enhanced treatment and protection of groundwater quality, Department of Ecology will now accept the following bioretention soil mix guidelines: a CEC ≥ 5 meq/100 grams of dry soil; 8-10 percent organic matter content; 2-5 percent fines; a maximum of 12 inches per hour initial (measured) infiltration rate; and a minimum soil depth of 18 inches with the above qualities (O'Brien, 2008).

3.2 The Aggregate Component of the Bioretention Soil Mix

The percent fines (aggregate passing the 200 sieve) in a BSM is important for proper system performance and requires particular attention. Presence of some fine material improves water retention, nutrient exchange and, as a result, the growing characteristics of soils. Smaller aggregate also increase receptor sites for adsorbing pollutants. In contrast, fine material strongly controls hydraulic conductivity and a small increase as a percentage of total aggregate can reduce hydraulic conductivity below rates needed for proper system draw-down.
Results from the four utility and screen sand samples suggest that:

- Sand with very low percent fines (Green Earth C33 washed sand at 1 percent fines) has hydraulic conductivities (shown in Table 1 as Average Permeability) that are too high.
- Sand with percent fines approaching 5 percent has a hydraulic conductivity that is too low.
- Sand with fines in the range of 2 to 4 percent (Green Earth screen sand and Miles utility sand) provide hydraulic conductivities that are within or very close to the desired range (See Table 1).

Table 1: Bioretention soil mix data summary

	Organic Content (%)				Grain Size Summary						
Sample Identification	before perm. test	after perm. test	Percent Compost (volume)	Percent Aggregate (volume)	D_{10} (mm)	D_{60} (mm)	D_{90} (mm)	Coefficient of Uniformity (Cu)*	Percent Fines	Maximum Dry Density (pct)	Average Permeability (in/hour)
Fred Hill Screen Sand + Compost	8.3	6.3	40	60	0.17	0.91	3.1	5.5	4.6	111	1.3
Green Earth C33 Washed Sand + Compost	8.8	6.2	40	60	0.27	1.2	3.5	4.4	1.0	108	27
Green Earth Screen Sand + Compost	9.6	--	40	60	0.19	0.55	1.0	2.9	2.4	102	13
Miles S&G Utility Sand	8.9	--	40	60	0.13	0.73	2.7	5.7	3.7	104	5.6

(*The coefficient of Uniformity is a measure of variation in particle sizes of mineral aggregate. The coefficient is defined as the ratio of the sieve size that will permit passage of 60% of the mineral aggregate by weight to the sieve size that will permit passage of 10% of the mineral aggregate by weight (D_{60}/D_{10}). A uniformity coefficient of 1.00 denotes a mineral aggregate having particle grains all the same size and numbers increasingly greater than one denote increasingly less uniformity.)

Overall gradation is important for BSM performance as well. The soil mix will likely infiltrate too rapidly if the aggregate component is a uniform particle size. Specifically, a uniformly graded, fine-grained material will have relatively low hydraulic conductivity (K). A uniformly graded, coarse-grained material will have a relatively high K. However, a well-graded material that appears coarse-grained can have relatively low K. For example, the Green Earth screen sand looks finer than Fred Hill screen sand with the D_{10} about the same and D_{60} and D_{90} larger for Fred Hill. However, the Fred Hill screen sand is better graded (see Grain Size Distribution, Appendix 1), has more fines and a lower K by an order of magnitude (Robertson, 2007). The interplay between gradation and percent fines significantly influences hydraulic conductivity and an aggregate component with relatively low fines and adequate gradation should provide the appropriate balance between water retention hydraulic conductivity for bioretention systems.

3.3 Recommendations for the Aggregate Component of the Bioretention Soil Mix

A range of 2 to 4 percent passing the 200 sieve is ideal and fines should not be above 5 percent for a proper functioning specification.

According to ASTM D 2487-98 (Classification of Soils for Engineering Purposes (Unified Soil Classification System)), well-graded sand should have the following gradation coefficients: Coefficient of Uniformity ($C_u = D_{60}/D_{10}$) equal to or greater than 6 and the Coefficient of Curve ($Cc = (D_{30})^2/D_{60} \times D_{10}$) greater than or equal to 1 and less than or equal to 3.

Table 2 provides a general guideline for the aggregate component of a BSM specification in western Washington (Robertson, 2007). The well-graded utility or screen sand balanced with enough fines to provide adequate water retention and hydraulic conductivity described in Table 1 should provide appropriate infiltration, pollutant removal and plant growth characteristics for bioretention soil mixes. While this study attempts to provide a more standardized mix and minimize the need for laboratory analysis, additional testing may be required to verify appropriate hydraulic conductivity if the local jurisdiction or client requires.

Table 2: General guideline for BSM gradation

Sieve Size	Percent Passing
3/8”	100
#4	95-100
#10	75-90
#40	25-40
#100	4-10
#200	2-5

3.4 Phosphorus and Nitrogen

Research suggests that bioretention systems can export nitrate-nitrogen (Davis et al., 2001). Where nitrate is a concern, an under-drain can be elevated from the bottom of the bioretention facility and located within a gravel blanket to create a fluctuating anaerobic/aerobic zone below the drain pipe. With a suitable carbon source (e.g. wood chips mixed in the gravel) acting as an electron donor (energy source for bacteria), the anaerobic zone can promote denitrification and improve nitrate removal (Kim et al., 2003). Davis (2001) also showed improved nitrate removal by simply increasing the BSM depth to 24 or 36 inches.

Davis (2001) found that phosphorus export can be reduced or eliminated and removal capability improved by increasing the bioretention soil mix depth to 24 and 36 inches. However, for bioretention areas with under-drains and soil mix depths less than 24 inches, phosphorus export may be a concern. Recent research by Hunt (2006) suggests that laboratory analysis for plant or bio-available phosphorus may correlate with phosphorus export from bioretention areas. The test recommended for western Washington to measure available phosphorus is the Bray test (see Appendix 2 for description of test).

Phosphorus availability is one of several parameters to determine the risk of phosphorus transport from agricultural land to fresh water systems. The sum of this analysis results in a P index and includes rain fall, irrigation, erosion potential (i.e. slope, hydraulic conductivity, soil and crop management), and fertilizer application (Elrashidi, 2001). In properly designed bioretention systems, erosion, nutrient application and irrigation should not be of concern, especially once plants and soil structure are established. Accordingly, P availability is likely the single most important assessment to indicate potential P transport from bioretention areas.

Available P test results for west of the cascades are divided into the following categories:
Low: <20mg/kg
Medium: 20-40mg/kg
High: 40-100mg/kg
Excessive: >100 to 250mg/kg*
(Marx et al., 1999)
* Note: different sources report different thresholds for excessive levels of available phosphorus. The lower threshold (100mg/kg) is proposed by Soiltest Farm Consultants, Inc. and the higher threshold (250 mg/kg) by Marx (1999).

Excessive levels of available P (>100 to 250mg/kg) suggest that bio-available phosphorus can exceed plant need or uptake and contribute to the pool of water soluble P that may be present in surface flow or soil water effluent (Stevens, 2008). Two of the three samples tested are at or slightly above the lower end of the excessive level indicating that when these soils are initially placed, phosphorus may be present in effluent if there is an under-drain flow release (see Table 3). Additional work is needed to correlate these agricultural tests in bioretention systems and to test available P when a bioretention soil mix is placed and then after the soil is planted and soil structure is improving.

Biosolids and manure composts can be higher in bio-available phosphorus than compost derived from yard or plant waste. Accordingly, biosolids or manure compost in bioretention areas are not recommended in order to reduce the possibility of exporting bio-available phosphorus in effluent.

Table 3: Available phosphorus and CEC test results for selected bioretention soil mixes

SAMPLE I.D.	Lab #	Bray P* (mg/kg)	Total P** (percent)	2:1 water Soluble P*** (mg/kg)	CEC (meq/100g)
FRED HILL, POULSBO SCREEN SAND 60% SAND, 40% COMPOST	7930	118	0.06	1.66	11.2
GREEN EARTH, BELLINGHAM C33 SAND 60% SAND, 40% COMPOST	7931	75	0.06	2.40	8.1
MILES SAND & GRAVEL UTILITY SAND 60% SAND, 40% COMPOST	7932	98	0.05	2.28	7.9
MILES SAND & GRAVEL UTILITY SAND	7933	12	0.03	0.44	5.8
FRED HILL, POULSBO SCREEN SAND	7934	12	0.03	0.44	5.3
GREEN EARTH, BELLINGHAM C33 SAND	7935	12	0.03	0.10	3.5

See below and Appendix 2 for more detail on test procedures.
*Bray Extraction: Typical values in acidic soils range from 10 to 200 mg/kg. Values greater than 250 mg/kg can be considered excessive.
**Total Phosphorus: Total P in soils ranges typically from 200 to 2,000 mg/kg. Composts and materials with high organic matter will run up to 5000 mg/kg.
***Water Soluble Phosphorus: This method only measures dissolved Ortho-P. The values are always very low due to the many adsorption and precipitation reactions to which phosphorus is susceptible. Ortho-P in natural waters seldom exceeds 0.5 mg/L, in 2:1 soil extractions, soluble P may reach 10 mg/kg.

3.5 Cation exchange capacity

The cation exchange capacity (CEC) is a measure of how many positively charged elements or cations (e.g. magnesium (Mg^{+2}), calcium (Ca^{+2}) and potassium (K^{+1})) soil can retain. Clay and organic material are the primary soil constituents providing receptor sites for cations and to a large degree determine CEC. One of the parameters for determining site suitability for stormwater infiltration treatment systems is CEC. Site Suitability Criteria #6 in the Stormwater Management Manual for Western Washington requires that soil CEC must be ≥ 5 milliequivalents/100 g dry soil (Ecology, 2005). All soil mixes tested for this analysis exceed the Site Suitability Criteria #6 requirement.

3.6 Compost

Compost is the other primary component of the BSM. Compost used in bioretention areas should be stable, mature and derived from organic waste materials including yard debris, wood wastes or other organic materials that meet the intent of the organic soil amendment specification. Compost stability indicates the level of microbial activity in the compost and is measured by the amount of CO_2 produced over a given period of time by a sample in a closed container. Unstable compost can render nutrients temporarily unavailable and create objectionable odors (WORC, 2003). Compost maturity refers to its ability to support healthy plant growth (and absence of any of the phytotoxic effects sometimes found in immature or unstable composts), and is measured by standard seed germination and growth tests. Compost production in Washington is regulated with minimum compost quality standards established under WAC 173-350 “Solid Waste Handling Standards” in 173-350-220 “Composting Facilities” (standards for time and temperature, pathogens, inerts, pH, stability, and metal contaminants) and 173-350-100 “Definitions” (defines Type 1, 2, 3, and 4 feedstocks). WAC 173-350 is available online at http:/www.ecy.wa.gov/programs/swfa/compost Any compost used for BSM should either be produced by a Washington permitted composting facility under this WAC or at least meet the pathogen and contaminant standards in the WAC.

In the absence of quantitative testing, compost quality can be determined by examining the material and qualitative tests. A simple way to judge compost quality is to smell and examine the finished product, which should have the following characteristics (WORC, 2003):

- Earthy smell that is not sour, sweet or ammonia like.
- Brown to black in color.
- Mixed particle sizes.
- Stable temperature and does not get hot when re-wetted.
- Crumbly texture.

Quantitative tests and producer documentation should have the following specifications:

- Material must be in compliance with WAC chapter 173-350 section 220, and be made from Type 1, 2, or 3 feedstock. Type 1 feedstock is recycled plant waste, including agricultural, yard, pre-consumer food, and cardboard; Type 2 is manure and bedding; Type 3 is post-consumer food, biosolids (sewage sludge), and other materials judged low in contaminants but potentially high in pathogens. Type 4 feedstock is mixed municipal solid waste, industrial solid wastes and other materials judged high risk for toxics, contaminants or pathogens.
- Organic matter content between 45% and 65% as determined by loss of ignition test method.
- pH between 5.5 and 8.0.
- Carbon:nitrogen ratio between 20:1 and 25:1 for most landscapes. A CN ratio of 30:1 to 35:1 is preferred for native woody plantings, especially in restoration projects, because it supports these plants and minimizes weed growth.
- Maximum electrical conductivity of 6 mmhos/cm (or 4 mmhos/cm for sites east of the Cascades where there is less rainfall to leach salts from BSM).
- Moisture content range between 35 and 50%.
- No viable weed seeds.
- Manufactured inert material (plastic, concrete, ceramics, etc.) should be less than 1% on a dry weight or volume basis (as required by WAC 173-350-220).

- Metals should not be in excess of limits in the following table (from WAC 173-350-220).

Metal	Limit (mg/kg dry weight)
Arsenic	≤ 20 ppm
Cadmium	≤ 10 ppm
Copper	≤ 750 ppm
Lead	≤ 150 ppm
Mercury	≤ 8 ppm
Molybdenum	≤ 9 ppm
Nickel	≤ 210 ppm
Selenium1	≤ 18 ppm
Zinc	≤ 1400 ppm

In the last two years both the Washington Department and of Transportation (WSDOT) and the City of Seattle have adopted specifications for compost. Both specifications rely on the US Composting Council's (USCC) "Seal of Testing Assurance" (STA) testing protocols which use the USCC's "Testing Methods for the Examination of Compost and Composting" (TMECC tests). In some cases the TMECC tests replicate existing ASTM tests (for example Loss-on-Ignition Organic Matter). In others (e.g. compost maturity) they have established a peer-reviewed national standard method where none previously existed. Currently, most but not all Washington composting facilities west of the Cascades, and some east, subscribe to the STA testing program. Additionally, most soil testing laboratories in this region can perform the TMECC tests. Table 4 compares Seattle and WSDOT specifications and TMECC test methods they require.

Table 4: Comparison of compost test methods

Parameter	Seattle Bioretention Compost spec	WSDOT Roadside Planting Compost spec	Testing method specified	Notes
Particle size (min. and max. percentages passing these screens)	passing 1" 99% - 100% passing 5/8" 90% - 100% passing 1/4" 40% - 90%	passing 2" 100% passing 1" 95% - 100% passing 5/8" 90% -100% passing 1/4" 75% -100%	TMECC 02.02-B "Sample Sieving for Aggregate Size Classification"	This is the WSDOT "Fine compost" spec – they also spec a larger "Coarse compost" for surface applications in erosion control.
pH	5.5 – 8.0	6.0 – 8.5	TMECC 04.11-A "1:5 Slurry pH"	
Inerts (plastic, concrete, ceramincs, metal, etc.)	< 1%	< 1%	TMECC03.08-A " Classification of Inerts by Sieve Size"	This is as required by WAC 173-350-220
Organic Matter	45-65%	minimum 40%	TMECC05.07A "Loss-On-Ignition Organic Matter Method"	Composts produced from essentially 100% organic feedstocks (no soil) test in the 45-65% range.
Soluble Salts (= EC or electrical conductivity)	≤ 6.0 mmhos/cm	≤ 4.0 mmhos/cm	TMECC 04.10-A "Electrical Conductivity, 1:5 Slurry Method, Mass Basis"	East of the Cascades, where there is less rainfall to leach salts from soil, EC should be held below 4 mmhos/cm.

Parameter	Seattle Bioretention Compost spec	WSDOT Roadside Planting Compost spec	Testing method specified	Notes
Maturity	> 80%	>80%	TMECC05.05-A "Germination and Vigor"	Both allow the Engineer to verify compost load maturity on delivery using the Sovita Compost Maturity Test, to score 6 or above on that test.
Stabiltiy	≤ 7 mg CO_2-C/g	≤ 7 mg CO_2-C/g	TMECC 05.08-B "Carbon Dioxide Evolution Rate"	
Carbon to Nitrogen Ratio	< 25:1 Engineer may specify C:N up to 35:1 for projects planted entirely with Puget Sound native species.	Not required	TMECC 04.01 "Total Carbon" and TMECC 04.02D "Total Kjeldahl Nitrogen"	
Feedstocks	Min 65% Type 1 feedstock Max 35% Type 3, excluding biosloilds	Min 65% Type 1 Max 35% Type 2 plus food waste or biosolids	WAC 173-350-100 definitions	Seattle decided to exclude manure (Type 2) and biosolids (in Type 3) to limit soluble n and P in bioretention mixes.

4.0 Additional factors influencing bioretention soil mix infiltration and next steps

Other important factors influencing BSM performance and guidelines were not examined in this review and analysis:

1) *Growing characteristics of the selected BSM*. Plants should be selected carefully for sandy compost mixes with hydraulic conductivities in the recommended range. These soils drain rapidly and have low field capacity, so native plants and cultivars (particularly in the upper, drier planting zones of bioretention areas) should be adapted to wet soils in the winter, as well as the dry summer conditions. Additional research or site monitoring of various plants in bioretention areas will be useful to confirm appropriate plant selection where sandy, well-drained bioretention soil mixes are applied.

2) *Soil infiltration characteristics*. Infiltration is dependent on organic matter content, soil biota and plants, as well as texture and structure. Plant roots, macro fauna and microbes tunnel, excavate, penetrate and physically and chemically bond soil particles to form stable aggregates that enhance soil structure and porosity (Soil and Water Conservation Society, 2000). While the development of soil structure and soil water characteristics are well understood in agricultural and horticultural settings, little or nothing is known about the development of soil structure in bioretention areas subject to regular stormwater pollutant inputs. Very limited data suggest that infiltration rates may improve in bioretention areas and plants and soil biota that influence soil structure may play an important role in maintaining or improving infiltration in bioretention systems (City of Portland Bureau of Environmental Services, 2006).

3) A growing body of research indicates that bioretention systems are an excellent water quality treatment approach with very good removal capability for metals, organics, oil and grease, and

bacteria. Total phosphorus and total nitrogen removal in bioretention is good compared to other stormwater treatment practices; however, nitrate and phosphate removal can be variable or poor unless specific design features, such as increased depth of BSM profile or an elevated under-drain, are incorporated (Davis et al., 2001; Hong, 2002; Hunt et al.; Kim et al., 2003). Additional research is needed on the role of plants and soil additives that may better manage nitrate and phosphate as well as maintain (or even improve) soil structure and infiltration rates over time.

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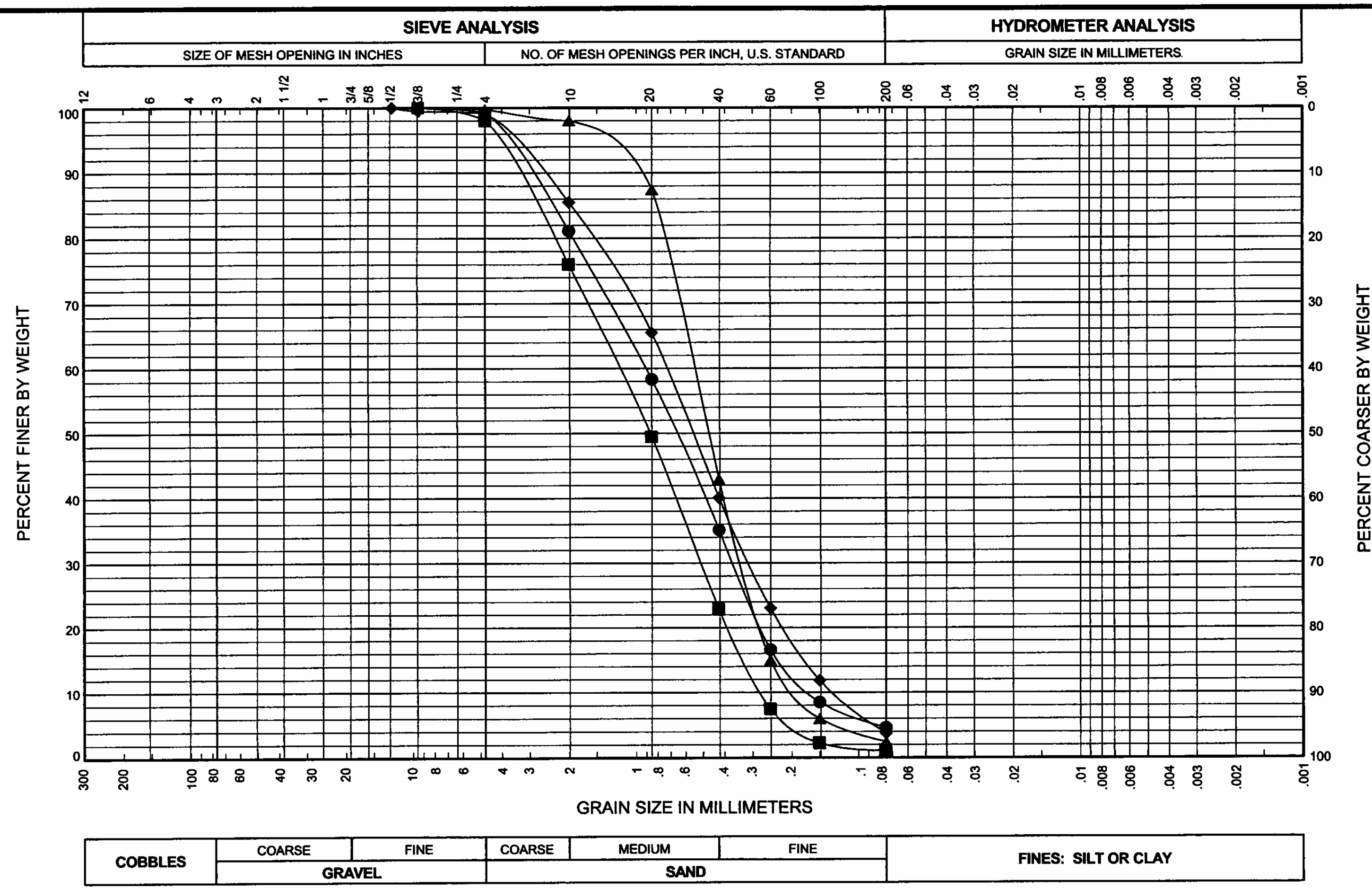
Appendix 1

Bioretention Soil Mix Permeability Testing
Shannon and Wilson



BORING AND SAMPLE NO.	U.S.C.S. SYMBOL	SAMPLE DESCRIPTION	FINES %	NAT. W.C. %	LL %	PL %	PI %
● Fred Hill Screen Sand	SP	Light gray SAND, trace of silt and gravel	4.6	3.6			
■ Green Earth C33 Washed Sand	SP	Gray SAND, trace of gravel and silt	1.0	5.2			
▲ Green Earth, Screen Sand	SP	Gray, fine to medium SAND, trace of silt and gravel	2.4	6.0			
◆ Miles S&G Utility Sand	SP	Gray SAND, trace of silt and gravel	3.7	9.5			

Washington State University
Permeability Testing

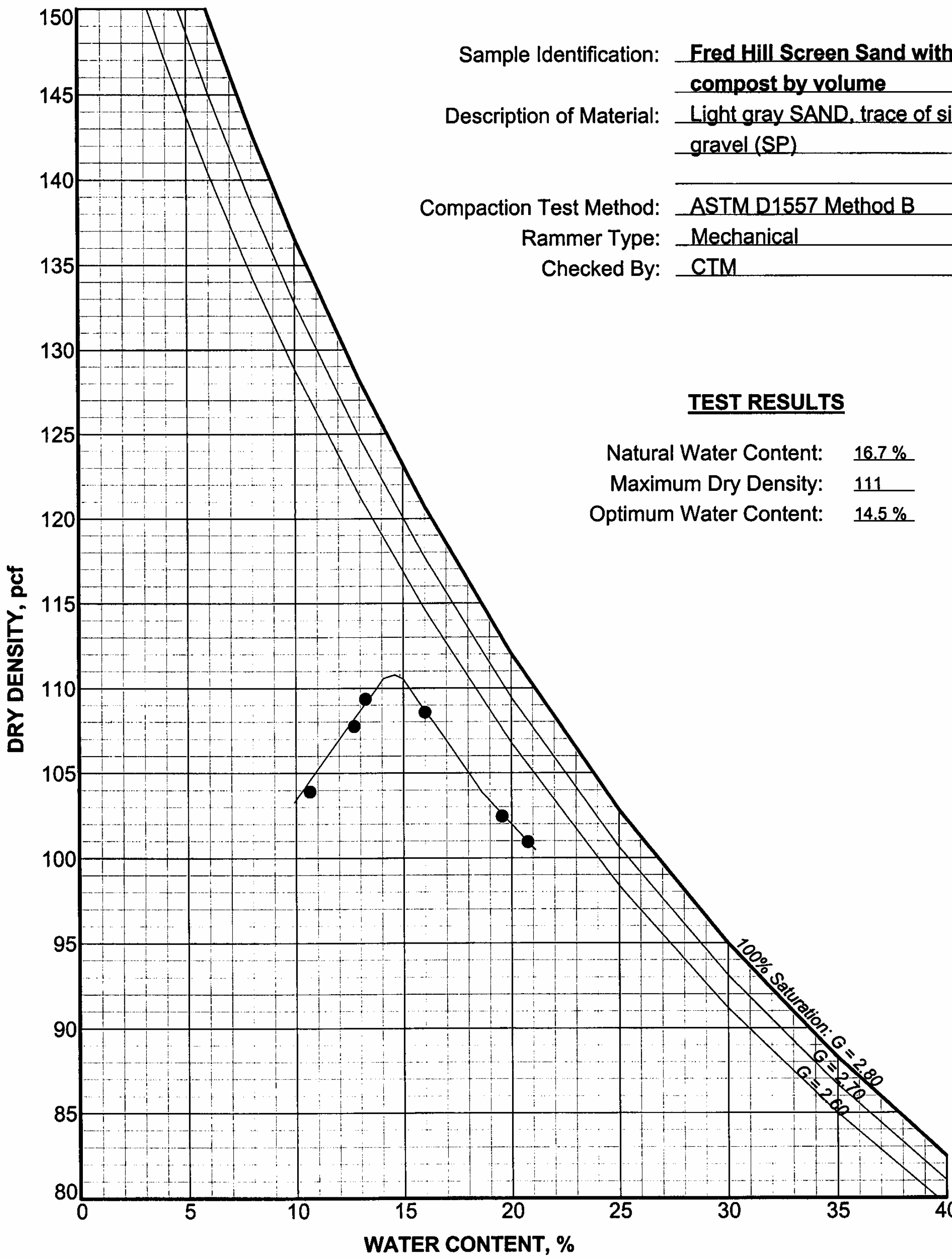
GRAIN SIZE DISTRIBUTION

April 2007 21-1-08824-026

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. 1

Washington State University



Sample Identification: Fred Hill Screen Sand with 40% compost by volume

Description of Material: Light gray SAND, trace of silt and gravel (SP)

Compaction Test Method: ASTM D1557 Method B

Rammer Type: Mechanical

Checked By: CTM

TEST RESULTS

Natural Water Content: 16.7 %

Maximum Dry Density: 111

Optimum Water Content: 14.5 %

OTHER TEST RESULTS

GRAIN SIZE ANALYSES: % Gravel: 0.8

% Sand: 94.6

% Fines: 4.6

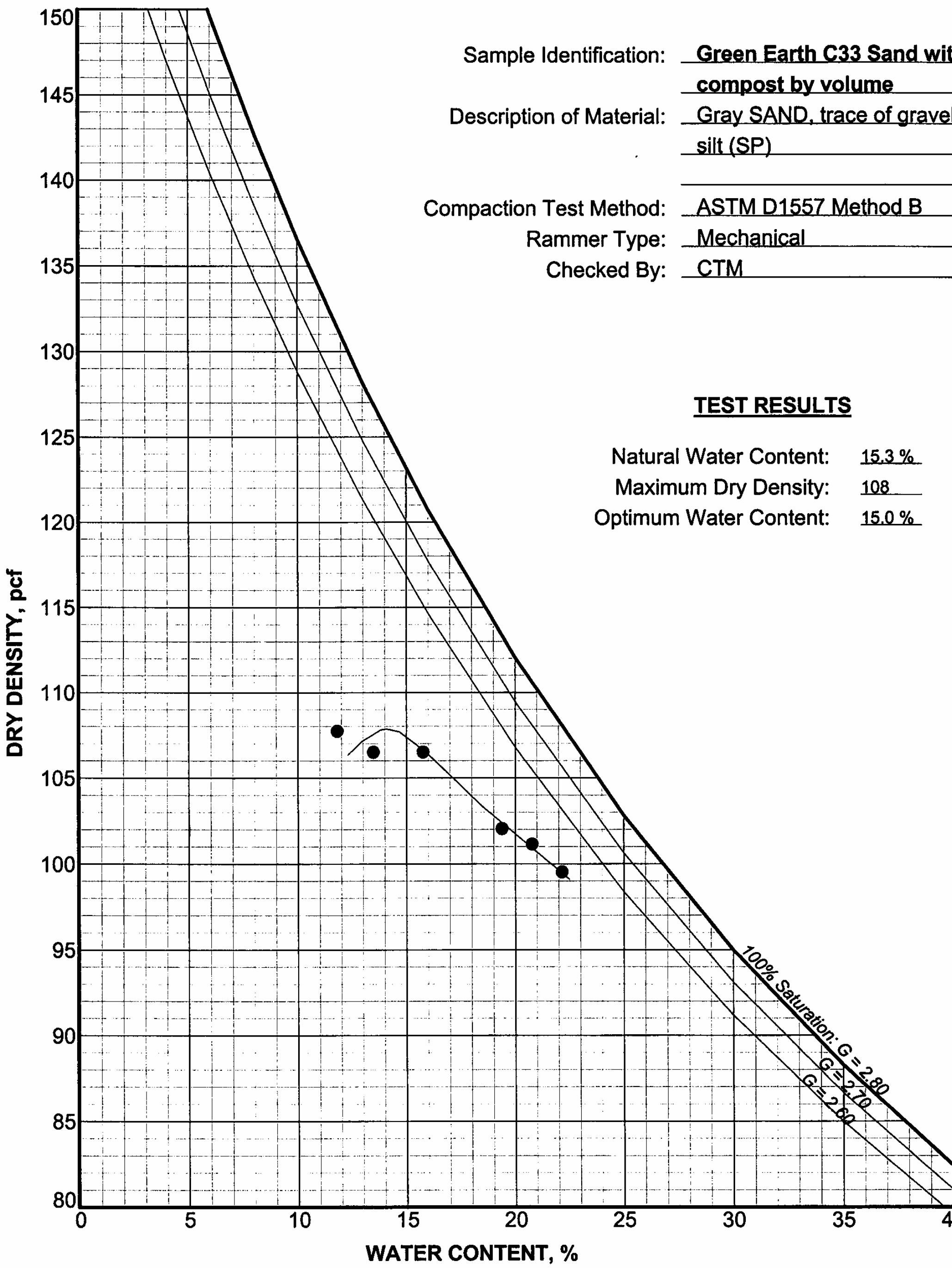
Washington State University
Permeability Testing

MOISTURE-DENSITY TEST

April 2007 21-1-08824-026

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. 2



Sample Identification: **Green Earth C33 Sand with 40% compost by volume**

Description of Material: Gray SAND, trace of gravel and silt (SP)

Compaction Test Method: ASTM D1557 Method B

Rammer Type: Mechanical

Checked By: CTM

TEST RESULTS

Natural Water Content: 15.3 %

Maximum Dry Density: 108

Optimum Water Content: 15.0 %

OTHER TEST RESULTS

GRAIN SIZE ANALYSES:

% Gravel: 2.0

% Sand: 97.0

% Fines: 1.0

Washington State University
Permeability Testing

MOISTURE-DENSITY TEST

April 2007 21-1-08824-026

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. 3

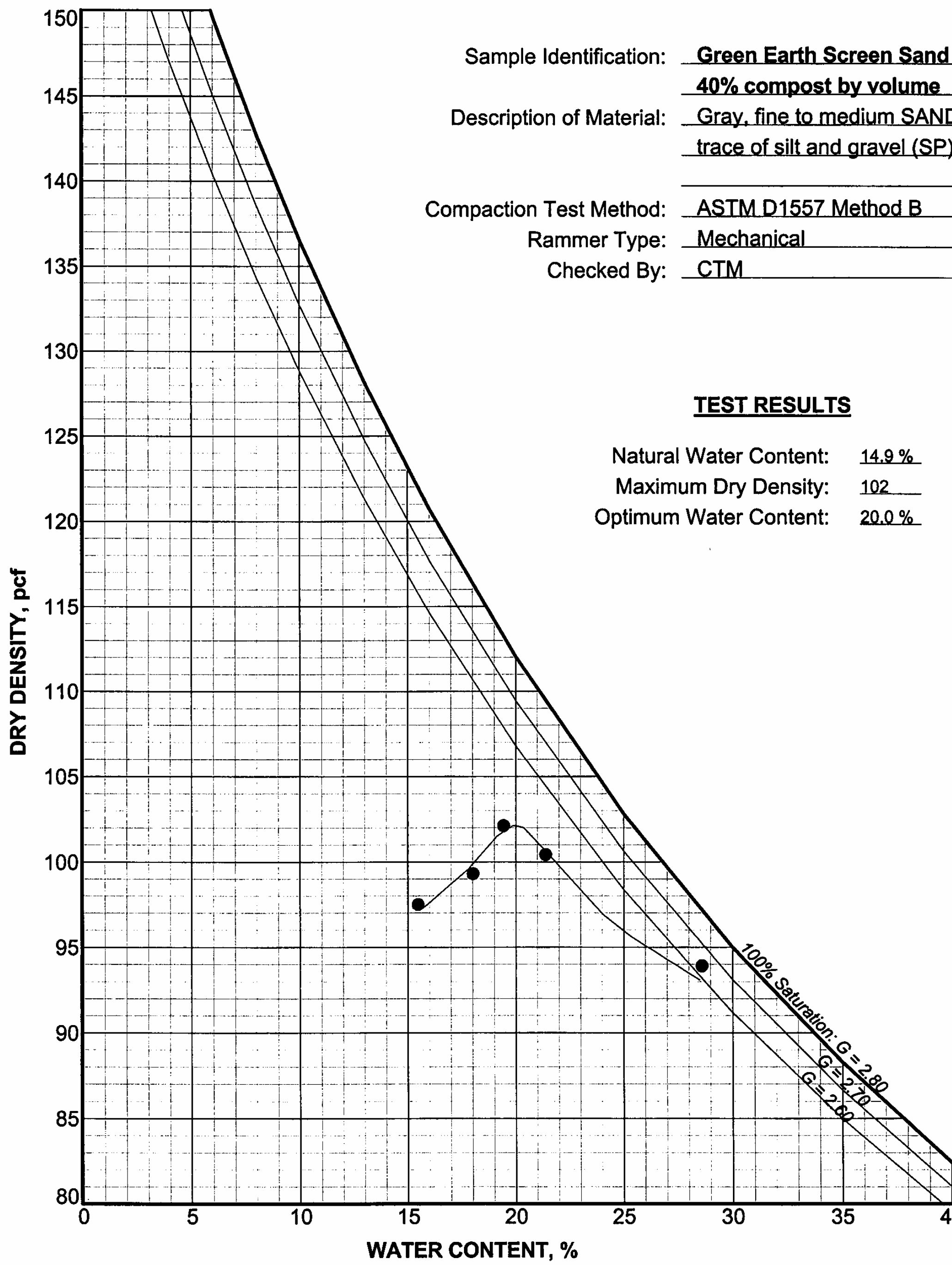
Sample Identification: **Green Earth Screen Sand with 40% compost by volume**

Description of Material: Gray, fine to medium SAND, trace of silt and gravel (SP)

Compaction Test Method: ASTM D1557 Method B

Rammer Type: Mechanical

Checked By: CTM



TEST RESULTS

Natural Water Content: 14.9 %

Maximum Dry Density: 102

Optimum Water Content: 20.0 %

OTHER TEST RESULTS

GRAIN SIZE ANALYSES:

% Gravel: 0.3

% Sand: 97.3

% Fines: 2.4

Washington State University
Permeability Testing

MOISTURE-DENSITY TEST

April 2007 21-1-08824-026

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. 4

Sample Identification: **Miles S&G Utility Sand with 40% compost (by volume)**

Description of Material: Gray SAND, trace of silt and gravel (SP)

Compaction Test Method: ASTM D1557 Method B

Rammer Type: Mechanical

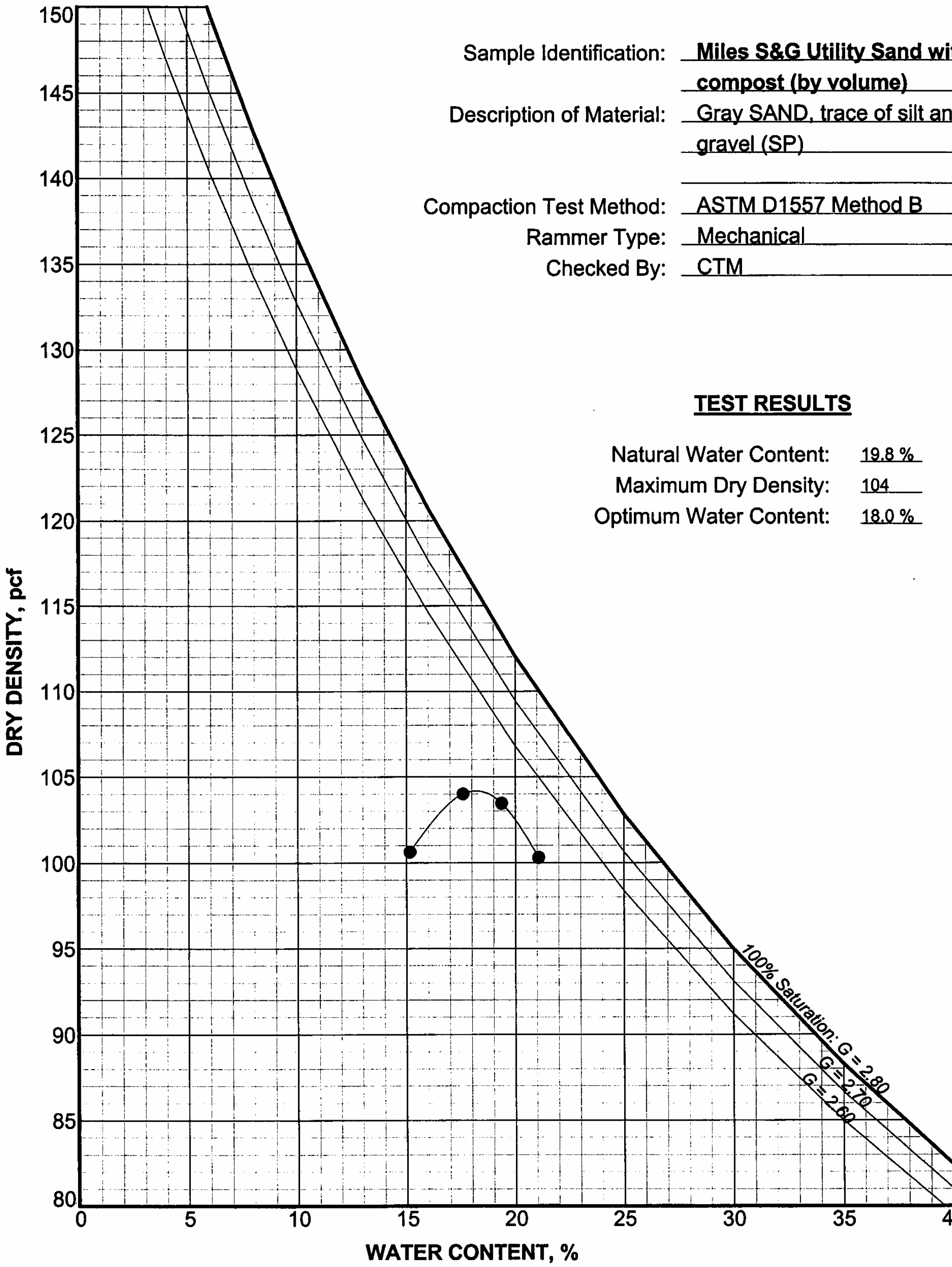
Checked By: CTM

TEST RESULTS

Natural Water Content: 19.8 %

Maximum Dry Density: 104

Optimum Water Content: 18.0 %



OTHER TEST RESULTS

GRAIN SIZE ANALYSES:

% Gravel: 0.9

% Sand: 95.4

% Fines: 3.7

Washington State University
Permeability Testing

MOISTURE-DENSITY TEST

April 2007 21-1-08824-026

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. 5

Table 1

SHANNON & WILSON, INC. GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

Project	WSU Perm	Job No.	21-1-08824-026		
Boring No.	Fred Hill	Test By	JFL	On	02/21/07
Sample No.	Screen Sand	Comp By	JFL	On	
Depth, Ft.	85%	Check By		On	

PERMEABILITY TEST ON GRANULAR SOIL
CONSTANT HEAD
ASTM D 2434

Specimen Data

Height (cm)	11.64
Diameter (cm)	10.10
Area (cm^2)	80.07
Volume (cm^3)	932.38

Sample Classification

Light gray SAND, trace of silt and gravel; contains 40% compost by volume

Permeameter Dimensions

I.D. of Reservior (cm)	10.10
O.D. of Tube (cm)	1.58
Area (cm^2)	78.11
Sample Length (cm)	11.64

Remarks

85% Compaction

Moisture Content

	Before	After
Wet + tare (g)	88.09	2035.17
Dry + tare (g)	78.61	1605.80
Tare (g)	3.16	225.28
mc (%)	12.6%	31.1%

Density Determination

Initial Wet Weight (g)	1581	
Final Wet Weight (g)	0	
Est. Specific Gravity	2.7	
Dry Unit Weight, γ_d (pcf)	94.0	
Compacted Unit Weight, γ_m (pcf)	105.9	
Saturated Unit Weight, γ_{sat} (pcf)	0.0	
Maximum Dry Density, γ_{max} (pcf)	111	(estimated)
Relative Compaction (%)	85.0	(estimated)
Temperature (°C)	21	

Test No.	Reservoir Level		Δh	H	t	Q	I	Q/at	k (in/hr)
	h_1 (cm)	h_2 (cm)	(cm)	(cm)	(s)	(cm^3)			
1	53.2	52.3	0.9	1.5	5400	72.1	0.13	1.7E-04	1.83E+00
2	52.3	51.2	1.1	2.0	5280	88.1	0.17	2.1E-04	1.72E+00
3	51.2	49.8	1.4	2.5	5400	112.1	0.21	2.6E-04	1.71E+00
4	48.9	47.8	1.1	3.0	4080	88.1	0.26	2.7E-04	1.48E+00
5	47.6	46.2	1.4	3.5	4260	112.1	0.30	3.3E-04	1.55E+00
6	46.2	41.9	4.3	4.0	10440	344.3	0.34	4.1E-04	1.70E+00
7	42.0	38.8	3.2	4.5	9270	256.2	0.39	3.5E-04	1.27E+00
8	38.6	35.4	3.2	5.0	9720	256.2	0.43	3.3E-04	1.09E+00
9	54.4	51.5	2.9	5.5	9720	232.2	0.47	3.0E-04	8.95E-01
10	54.8	53.2	1.6	6.0	3540	128.1	0.52	4.5E-04	1.24E+00
11	54.8	30.5	24.3	6.0	69660	1945.7	0.52	3.5E-04	9.60E-01
12	30.4	28.3	2.1	7.0	6720	168.1	0.60	3.1E-04	7.37E-01
13	28.1	25.4	2.7	8.0	7500	216.2	0.69	3.6E-04	7.43E-01
14	53.2	50.8	2.4	9.0	3240	192.2	0.77	7.4E-04	1.36E+00
15	50.6	46.7	3.9	10.0	5340	312.3	0.86	7.3E-04	1.21E+00
16	46.7	44.7	2.0	11.0	2580	160.1	0.94	7.8E-04	1.16E+00
17	44.7	42.7	2.0	12.0	2520	160.1	1.03	7.9E-04	1.09E+00
18	55.5	47.8	7.7	13.0	9120	616.5	1.12	8.4E-04	1.07E+00
19	47.7	42.2	5.5	14.0	6900	440.4	1.20	8.0E-04	9.40E-01
20	42.1	40.2	1.9	15.0	2280	152.1	1.29	8.3E-04	9.17E-01
21	40.0	32.1	7.9	16.0	9300	632.6	1.37	8.5E-04	8.76E-01
22			0.0	17.0		0.0	1.46	#DIV/0!	#DIV/0!
23			0.0			0.0	0.00	#DIV/0!	#DIV/0!
24			0.0			0.0	0.00	#DIV/0!	#DIV/0!
								Average k	1.3E+00

Note:
h_1 is the initial reservoir water level.
h_2 is the final reservoir water level.
Δh is the change in reservoir water level during the test.
H is the head difference across the specimen.
t is the elapse time for changing water level.
Q is the volume of water discharged.
I is the hydraulic gradient.
a is the cross-section area of the specimen.
k is the hydraulic conductivity of the specimen.

Table 2

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

Project	WSU Perm	Job No.			21-1-08824-026
Boring No.	Green Earth	Test By	JFL	On	04/02/07
Sample No.	C33	Comp By	JFL	On	04/02/07
Depth, Ft.	n/a	Check By		On	

PERMEABILITY TEST ON GRANULAR SOIL
CONSTANT HEAD
ASTM D 2434

Specimen Data

Height (cm)	11.64
Diameter (cm)	10.10
Area (cm^2)	80.07
Volume (cm^3)	932.38

Sample Classification

Gray SAND, trace of silt and gravel; with 40% compost by volume; SP.

Permeameter Dimensions

I.D. of Reservior (cm)	10.10
O.D. of Tube (cm)	1.58
Area (cm^2)	78.11
Sample Length (cm)	11.64

Remarks

85% compaction in 5 lifts

Moisture Content

	Before	After
Wet + tare (g)	407.92	2011.92
Dry + tare (g)	367.16	1601.20
Tare (g)	100.32	241.90
mc (%)	15.3%	30.2%

Density Determination

Initial Wet Weight (g)	1573	
Final Wet Weight (g)	1770	
Est. Specific Gravity	2.7	
Dry Unit Weight, γ_d (pcf)	91.4	
Compacted Unit Weight, γ_m (pcf)	105.3	
Saturated Unit Weight, γ_{sat} (pcf)	118.5	
Maximum Dry Density, γ_{max} (pcf)	108	(estimated)
Relative Compaction (%)	85.0	(estimated)
Temperature (°C)	21	

Test No.	Reservoir Level		Δh	H	t	Q	I	Q/at	k (in/hr)
	h_1 (cm)	h_2 (cm)	(cm)	(cm)	(s)	(cm^3)			
1	53.6	49.8	3.9	1.0	6120	308.3	0.09	6.3E-04	1.04E+01
2	49.7	44.6	5.1	1.5	3180	408.4	0.13	1.6E-03	1.76E+01
3	44.5	37.4	7.1	2.0	3120	568.5	0.17	2.3E-03	1.88E+01
4	37.3	28.4	8.9	2.5	2700	712.6	0.21	3.3E-03	2.18E+01
5	28.3	25.0	3.3	3.0	780	264.2	0.26	4.2E-03	2.33E+01
6	24.8	20.5	4.3	3.5	810	344.3	0.30	5.3E-03	2.50E+01
7	20.3	12.3	8.0	4.0	1320	640.6	0.34	6.1E-03	2.50E+01
8	53.2	47.5	5.7	4.5	720	456.4	0.39	7.9E-03	2.90E+01
9	47.4	42.7	4.7	5.0	510	376.3	0.43	9.2E-03	3.04E+01
10	42.3	39.2	3.1	5.5	300	248.2	0.47	1.0E-02	3.10E+01
11	38.8	35.1	3.7	6.0	330	296.3	0.52	1.1E-02	3.08E+01
12	34.7	19.7	15.0	7.0	1140	1201.0	0.60	1.3E-02	3.10E+01
13	19.3	11.7	7.6	8.0	510	608.5	0.69	1.5E-02	3.07E+01
14	11.1	8.0	3.1	9.0	180	248.2	0.77	1.7E-02	3.16E+01
15	51.0	47.4	3.6	10.0	180	288.3	0.86	2.0E-02	3.30E+01
16	46.5	12.1	34.4	11.0	1560	2754.4	0.94	2.2E-02	3.31E+01
17	54.0	42.2	11.8	12.0	450	944.8	1.03	2.6E-02	3.61E+01
18	42.0	38.7	3.3	13.0	120	264.2	1.12	2.8E-02	3.49E+01
19	38.1	34.6	3.5	14.0	120	280.2	1.20	2.9E-02	3.44E+01
20	33.9	30.2	3.7	15.0	120	296.3	1.29	3.1E-02	3.39E+01
21	29.3	25.2	4.1	16.0	120	328.3	1.37	3.4E-02	3.52E+01
22	24.6	21.4	3.2	17.0	90	256.2	1.46	3.6E-02	3.45E+01
23	20.3	17.1	3.2	1.5	2640	256.2	0.13	1.2E-03	1.3E+01
24			0.0			0.0	0.00	#DIV/0!	#DIV/0!
								Average k	2.7E+01

Note:
h_1 is the initial reservoir water level.
h_2 is the final reservoir water level.
Δh is the change in reservoir water level during the test.
H is the head difference across the specimen.
t is the elapse time for changing water level.
Q is the volume of water discharged.
I is the hydraulic gradient.
a is the cross-section area of the specimen.
k is the hydraulic conductivity of the specimen.

Table 3

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

Project	WSU Perm	Job No.		21-1-08824-026	
Boring No.	Green Earth	Test By	JFL	On	02/21/07
Sample No.	Screen Sand	Comp By	JFL	On	02/28/07
Depth, Ft.	n/a	Check By	CTM	On	

PERMEABILITY TEST ON GRANULAR SOIL
CONSTANT HEAD
ASTM D 2434

Specimen Data

Height (cm)	11.64
Diameter (cm)	10.10
Area (cm^2)	80.07
Volume (cm^3)	932.38

Sample Classification

Gray SAND, trace of silt and gravel; with 40% compost by volume; SP.

Permeameter Dimensions

I.D. of Reservior (cm)	10.10
O.D. of Tube (cm)	1.58
Area (cm^2)	78.11
Sample Length (cm)	11.64

Remarks

85% compaction in 5 lifts

Moisture Content

	Before	After
Wet + tare (g)	598.21	1953.63
Dry + tare (g)	519.51	1505.93
Tare (g)	112.91	214.97
mc (%)	19.4%	34.7%

Density Determination

Initial Wet Weight (g)	1553	
Final Wet Weight (g)	1739	
Est. Specific Gravity	2.7	
Dry Unit Weight, γ_d (pcf)	87.1	
Compacted Unit Weight, γ_m (pcf)	104.0	
Saturated Unit Weight, γ_{sat} (pcf)	116.4	
Maximum Dry Density, γ_{max} (pcf)	102	(estimated)
Relative Compaction (%)	85.4	(estimated)
Temperature (°C)	21	

Test No.	Reservoir Level		Δh	H	t	Q	I	Q/at	k (in/hr)
	h_1 (cm)	h_2 (cm)	(cm)	(cm)	(s)	(cm^3)			
1	53.6	47.7	5.9	1.5	7020	472.4	0.13	8.4E-04	9.25E+00
2	47.6	44.1	3.5	2.0	3000	280.2	0.17	1.2E-03	9.63E+00
3	44.0	38.0	6.0	2.5	3900	480.4	0.21	1.5E-03	1.02E+01
4	37.9	32.0	5.9	3.0	3180	472.4	0.26	1.9E-03	1.02E+01
5	31.9	24.2	7.7	3.5	3300	616.5	0.30	2.3E-03	1.10E+01
6	24.2	17.1	7.1	4.0	3120	568.5	0.34	2.3E-03	9.39E+00
7	16.9	9.4	7.5	4.5	3240	600.5	0.39	2.3E-03	8.49E+00
8	54.5	38.0	16.5	5.0	4200	1321.1	0.43	3.9E-03	1.30E+01
9	37.8	32.3	5.5	5.5	1380	440.4	0.47	4.0E-03	1.20E+01
10	32.0	24.7	7.3	6.0	1680	584.5	0.52	4.3E-03	1.20E+01
11	24.5	14.3	10.2	7.0	2040	816.7	0.60	5.0E-03	1.18E+01
12	54.3	40.4	13.9	8.0	1980	1113.0	0.69	7.0E-03	1.45E+01
13	36.4	26.4	10.0	8.0	1260	800.7	0.69	7.9E-03	1.64E+01
14	55.1	43.7	11.4	9.0	1020	912.8	0.77	1.1E-02	2.05E+01
15	43.4	36.5	6.9	10.0	660	552.5	0.86	1.0E-02	1.73E+01
16	36.2	26.9	9.3	11.0	840	744.6	0.94	1.1E-02	1.66E+01
17	26.4	19.2	7.2	12.0	600	576.5	1.03	1.2E-02	1.65E+01
18	18.5	13.0	5.5	13.0	420	440.4	1.12	1.3E-02	1.66E+01
19	54.4	49.4	5.0	14.0	300	400.3	1.20	1.7E-02	1.96E+01
20	49.0	41.7	7.3	15.0	420	584.5	1.29	1.7E-02	1.91E+01
21	41.3	35.8	5.5	16.0	300	440.4	1.37	1.8E-02	1.89E+01
22	35.4	29.6	5.8	17.0	300	464.4	1.46	1.9E-02	1.88E+01
23	14.9	12.1	2.8	4.5	720	224.2	0.39	3.9E-03	1.4E+01
24	11.7	9.5	2.3	1.5	3000	180.2	0.13	7.5E-04	8.3E+00
								Average k	1.3E+01

Note:
h_1 is the initial reservoir water level.
h_2 is the final reservoir water level.
Δh is the change in reservoir water level during the test.
H is the head difference across the specimen.
t is the elapse time for changing water level.
Q is the volume of water discharged.
I is the hydraulic gradient.
a is the cross-section area of the specimen.
k is the hydraulic conductivity of the specimen.

Table 4

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

Project	WSU Perm	Job No.			21-1-08824-026
Boring No.	Miles Sand	Test By	JFL	On	01/19/07
Sample No.	w/ compost	Comp By	JFL	On	01/31/07
Depth, Ft.	n/a	Check By	CTM	On	

PERMEABILITY TEST ON GRANULAR SOIL
CONSTANT HEAD
ASTM D 2434

Specimen Data

Height (cm)	11.64
Diameter (cm)	10.10
Area (cm^2)	80.07
Volume (cm^3)	932.38

Sample Classification

Gray SAND, trace of silt and gravel; with 40% compost by volume; SP.

Permeameter Dimensions

I.D. of Reservior (cm)	10.10
O.D. of Tube (cm)	1.58
Area (cm^2)	78.11
Sample Length (cm)	11.64

Remarks

85% compaction in 5 lifts

Moisture Content

	Before	After
Wet + tare (g)	604.11	1954.40
Dry + tare (g)	526.68	1522.01
Tare (g)	102.32	225.30
mc (%)	18.2%	33.3%

Density Determination

Initial Wet Weight (g)	1557	
Final Wet Weight (g)	1729	
Est. Specific Gravity	2.7	
Dry Unit Weight, γ_d (pcf)	88.2	
Compacted Unit Weight, γ_m (pcf)	104.3	
Saturated Unit Weight, γ_{sat} (pcf)	115.8	
Maximum Dry Density, γ_{max} (pcf)	104	(estimated)
Relative Compaction (%)	84.8	(estimated)
Temperature (°C)	21	

Test No.	Reservoir Level		Δh	H	t	Q	I	Q/at	k (in/hr)
	h_1 (cm)	h_2 (cm)	(cm)	(cm)	(s)	(cm^3)			
1	51.2	31.6	19.6	3.0	18540	1569.4	0.26	1.1E-03	5.8E+00
2	55.3	47.9	7.4	4.0	5100	592.5	0.34	1.5E-03	6.0E+00
3	54.1	44.6	9.5	5.0	4440	760.7	0.43	2.1E-03	7.1E+00
4	44.5	16.2	28.3	5.5	13920	2266.0	0.47	2.0E-03	6.1E+00
5	55.0	41.5	13.5	6.0	7140	1080.9	0.52	1.9E-03	5.2E+00
6	55.5	40.5	15.0	6.5	6540	1201.0	0.56	2.3E-03	5.8E+00
7	55.5	41.4	14.1	7.0	5640	1129.0	0.60	2.5E-03	5.9E+00
8	54.7	43.0	11.7	7.5	3960	936.8	0.64	3.0E-03	6.5E+00
9	55.2	38.0	17.2	8.0	6060	1377.2	0.69	2.8E-03	5.9E+00
10	55.0	42.0	13.0	8.5	3900	1040.9	0.73	3.3E-03	6.5E+00
11	54.2	42.6	11.6	9.0	3760	928.8	0.77	3.1E-03	5.7E+00
12	55.4	44.8	10.6	10.0	3840	848.7	0.86	2.8E-03	4.6E+00
13	55.3	35.2	20.1	11.0	7500	1609.4	0.94	2.7E-03	4.0E+00
14	55.1	53.7	1.4	12.0	300	112.1	1.03	4.7E-03	6.4E+00
15	55.1	36.9	18.2	12.0	5760	1457.3	1.03	3.2E-03	4.3E+00
16	54.8	42.1	12.7	13.0	3390	1016.9	1.12	3.7E-03	4.8E+00
17	54.5	46.2	8.3	14.0	2070	664.6	1.20	4.0E-03	4.7E+00
18	54.8	32.3	22.5	15.0	7260	1801.6	1.29	3.1E-03	3.4E+00
19	55.2	45.2	10.0	16.0	2520	800.7	1.37	4.0E-03	4.1E+00
20	53.1	45.4	7.7	16.0	1380	616.5	1.37	5.6E-03	5.8E+00
21	54.2	48.4	5.8	17.0	1080	464.4	1.46	5.4E-03	5.2E+00
22			0.0			0.0	0.00	#DIV/0!	#DIV/0!
23			0.0			0.0	0.00	#DIV/0!	#DIV/0!
								Average k	5.6E+00

Note:
h_1 is the initial reservoir water level.
h_2 is the final reservoir water level.
Δh is the change in reservoir water level during the test.
H is the head difference across the specimen.
t is the elapse time for changing water level.
Q is the volume of water discharged.
I is the hydraulic gradient.
a is the cross-section area of the specimen.
k is the hydraulic conductivity of the specimen.

Appendix 2

Explanation of Phosphorus Tests

Soiltest Farm Consultants, Inc.

Phosphorus tests
Bray Extraction
Reference: WREP 125, 2nd Ed. Pp 69-71
The Bray extractant is a dilute solution of HCl and NH4F adjusted to a pH of 2.6; phosphorus is determined calorimetrically. It is designed for use on acid soils and is used in Western Washington and Oregon to measure plant available P. The acidic nature of the solution readily dissolves carbonates and calcium phosphate minerals which makes it generally unsuitable for use in calcareous soils. Typical values in acidic soils range from 10 to 200 mg/kg. Values greater than 250 mg/kg can be considered excessive. Values in compost materials can easily run twice as high as soils.

Total Phosphorus
Reference: WREP 125, 2nd Ed. Pp 162-164.
The Nitric/Perchloric Wet Ashing method for total P analysis was used for the above tests. This method is a strong acid digest which solubilizes all P including available and mineral and organic P in the sample for determination by ICP. Total P in soils ranges typically from 200 to 2,000 mg/kg. Composts and materials with much plant matter will run up to 5000 mg/kg.

Water Soluble Phosphorus
A 2:1, distilled water to soil extraction was used to measure water soluble phosphorus. Soluble P represents that portion of the P pool that is capable of moving with the soil solution into the ground and/or surface water. There is a general relationship between soluble P and Extractable P, but the relationship generally has a strong site dependency. This method only measures dissolved Ortho-P. The values are always very low due to the many adsorption and precipitation reactions to which phosphorus is susceptible. Ortho-P in natural waters seldom exceeds 0.5 mg/L, in 2:1soil extractions, soluble P may reach 10 mg/kg.